NASA CR-66295

Report 1395

DEVELOPMENT AND PERFORMANCE OF A SMALL CROSSED-LOOP OMNIDIRECTIONAL UHF PROTOTYPE ANTENNA FOR A PENETROMETER - FINAL REPORT

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To National Aeronautics and Space Administration

1967 JAN 30 Job 482.11

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Summary

A turnstile antenna with isotropic-like radiation coverage was evaluated for use in an impact-measuring instrumented projectile. The antenna comprises a pair of orthogonal loops fed in phase quadrature. The loops are resonated by series capacitors and are mounted about a shielded spherical core containing a telemetry transmitter accelerometer, battery, and a directional coupler.

Two types of prototype test models of the antenna were fabricated to comply with the particular requirements of the radiation pattern and antenna-impedance tests. The pattern-test models are self-contained units comprising two antenna loops supported about a CW oscillator, a pair of batteries and a 3-db directional coupler all enclosed within the central core. The impedance-test models essentially comprise a single antenna loop about a central core, encapsulated in an epoxy-resin sphere. An antenna-feed cable is available at the surface of the encapsulant sphere for performing impedance measurements.

Radiation patterns and impedance of the test models were measured in free space and as the models approached, made contact with, and were immersed in a bed of dry masonry-grade sand. These tests were performed at approximately 250 Mhz, 350 Mhz, and 450 Mhz, the design frequencies for each pair of models.

The free-space radiation patterns indicate a 4 db variation of radiated power about the full direction sphere. The radiation patterns of the test models located near and submerged in the sand bed were somewhat masked by reflections from the sand-bed environment. These tests indicated that the minimum signal available in the submerged condition can be expected to be of the order of 10 db below the corresponding signal available in the free-space condition.

Impedance tests confirmed the calculations of the radiation power factor of the 250 Mhz model. The measured antenna efficiency for the 250 Mhz and 450 Mhz models are 12% and 34%, respectively: the efficiency of the 350 Mhz model was not measured because of a fault in construction. The results of the measurements of the radiation resistance and change of reactance of the 250 Mhz model near and submerged in the sand bed correspond with previous theoretical predictions.

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A comparison of the crossed-loop antenna with a four-dipole antenna in the form of a pair of turnstile radiators indicates the crossed-loop antenna is inherently the least sensitive to changes of dielectric constant of the environment encountered when in proximity with soil-like media.

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I. Introduction.

Some information regarding the physical properties of lunar or planetary surfaces is required prior to spacecraft landings and post-landing explorations. A research program conducted at the Langley Research Center of the National Aeronautics and Space Administration has shown that impact-measuring instrumented projectiles (penetrometers) can be used to evaluate physical properties such as surface hardness, penetrability and bearing strength.

A measurement technique has been devised by NASA whereby a penetrometer, comprising a piezo-electric acceleration sensor, modulator, FM transmitter, antenna, and battery power supply, impacts the unknown surface at a selected velocity. During the impact process, the transmitter is frequency modulated by the impact-acceleration sensor. The modulated RF output from the transmitter is then radiated by the antenna to a nearby space probe for retransmission to earth. Analysis of the impact-acceleration time-history signatures is then accomplished by a comparison with signatures of known terrestial surfaces, thereby relating the similar physical characteristics.

An omnidirectional antenna mounted in a spherical penetrometer package is required, since attitude stability or elaborate deployment techniques are not feasible, and transmission is required during impact regardless of penetrometer orientation. The antenna must operate reliably during a high-acceleration impact period and in varying proximity with or submersion in the surface material.

Wheeler Laboratories was selected by NASA to develop, design and fabricate a prototype omnidirectional antenna for the penetrometer. The objective of the initial phase of the contract was a general study of the possible methods of achieving an omnidirectional antenna system which conforms to the physical, electrical, and environmental requirements of the penetrometer. As a result of this study, WL recommended for the penetrometer application (WL Report 1291), a turnstile-mode antenna comprising a pair of crossed loops (magnetic dipoles) fed in quadrature phase.

The objective of the next phase of the contract was the development, fabrication and electrical-performance evaluation of prototype test models of the recommended turnstile-mode antenna; this

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report is the final report on this phase. The report presents a description of the proposed penetrometer antenna, a description of the two types of prototype test models of the antenna, a description of the electrical tests performed of these prototype test models, and the results of these tests.

The contract also required additional studies and tests of a different type of antenna designed for a similar application. NASA supplied drawings specifying the configuration of this particular antenna. A prototype model was fabricated and tested at WL. A description of this antenna, the tests performed, and the test results are presented in WL Report 1375.

II. Objectives of Program

Based on the prior general study and configuration proposed in WL Report 1291, a turnstile-mode antenna comprising a pair of crossed loops was selected for intensive study and evaluation. The requirements of this program are the development, fabrication and tests of prototype test models of the turnstile-mode crossed-loop antenna. The objectives of the program are the evaluation of the antenna performance in accordance with the specifications, and the confirmation of the theoretical estimates of antenna detuning during approach and immersion into a dielectric media in accordance with the earlier WL study. The detailed requirements and objectives are outlined in the NASA Statement of Work L-3833 for The Development, Design and Fabrication of Prototype Omnidirectional Transmitter Antennas.

Two general types of tests are required to evaluate the performance of the antenna; these are measurements of radiation patterns and antenna impedance. Because of the widely different test objectives, two types of prototype test models of the crossed-loop antenna are necessary. The configuration of each model is chosen to comply with the particular requirements of the different tests.

To accurately measure the radiation pattern of this omnidirectional antenna, the RF signal source and associated battery power supply, together with the directional coupler, must be contained within

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the central region of the antenna. With this arrangement, the measured radiation pattern is that of a completely isolated crossed-loop antenna, unperturbed by any feed or power cables.

Tests of the antenna impedance in the vicinity of a dielectric-air interface are required to confirm the predictions given in WL Report 1291. A complete crossed-loop antenna, as required for pattern tests, with a 3-db directional coupler as a feed circuit, is insensitive to tests of antenna detuning because most of the reflected signal does not appear at the input, but is dissipated in a termination on the isolated port of the coupler instead. Therefore, for the impedance tests, a test model comprising a single loop antenna fed by a coaxial cable oriented along the antenna neutral axis is used.

The two types of test models described in the next section were developed to operate at a single frequency within the frequency bands of 240 to 260 Mhz, 300 to 350 Mhz, and 430 to 460 Mhz, respectively. A specific design configuration is necessary for each frequency band because of the relatively narrow-band capabilities of the small loop antenna.

The major performance objectives of the prototype models operating in free space are:

1. Antenna reflection less than 6 db SWR,
2. Radiation pattern with a maximum to minimum ratio less than 4 db,
3. Antenna gain, averaged over the spherical radiation pattern, greater than -14 db, relative to dipole (4% efficiency),
4. Sufficient measurements of pattern and impedance characteristics are also required to determine the antenna performance as the antenna:
   (a) approaches and makes contact with a level surface of dry masonry-grade sand,
   (b) approaches and immerses to a depth of at least one-half wavelength in a bed of dry masonry-grade sand.

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III. Antenna Configuration.

A. Proposed Penetrometer Assembly.

The turnstile-mode crossed-loop antenna, as proposed in WL Report 1291 for detailed evaluation, is shown in a cutaway view in Fig. 1. At the center of the antenna assembly is a thin-walled spherical conducting shield or core, 2-3/4 inch diameter, intended to house an acceleration sensor, frequency-modulated transmitter, battery and directional coupler. (The design and packaging of these components is not included in the WL development program.) Two coupling loops are located on the surface of the core to couple the signal from the feed components within the core to the antenna loops surrounding the core. The two antenna loops, the radiating portions of the assembly, are located orthogonal to each other, in the planes of the coupling loops, and concentric about the central core. The antenna loops, nominally 3-5/16 inches diameter, comprise four thin conducting strips, approximately .007-inch thick by 3/4-inch wide, soldered to four metallized dielectric-slab capacitors. The area and thickness of the capacitors determine the series capacitance in the loop, and hence, the resonant frequency of the antenna loop.

A physical interference occurs at the overlap region of the two antenna loops because of both the cylindrical contour of the loops and the limited offset provided by the thickness of the capacitors. To provide a clearance between the antenna loops, the loop width is reduced at the overlap regions, as shown in Fig. 1. The two loops are prevented from contacting where they overlap by a spacer of low dielectric constant.

The whole assembly is encapsulated in a 4-inch diameter sphere of fiberglass-reinforced epoxy resin. The epoxy-resin encapsulant technique was specified by NASA. It provides a permanent support and protection of the antenna components at impact. In operational models of the penetrometer assemblies, removable leads are provided for a battery trickle charge and transmitter turn-off bias during shelf storage.

The RF-circuit diagram of the antenna and feed is shown in Fig. 2(a). The transmitter output is connected by a coaxial cable to

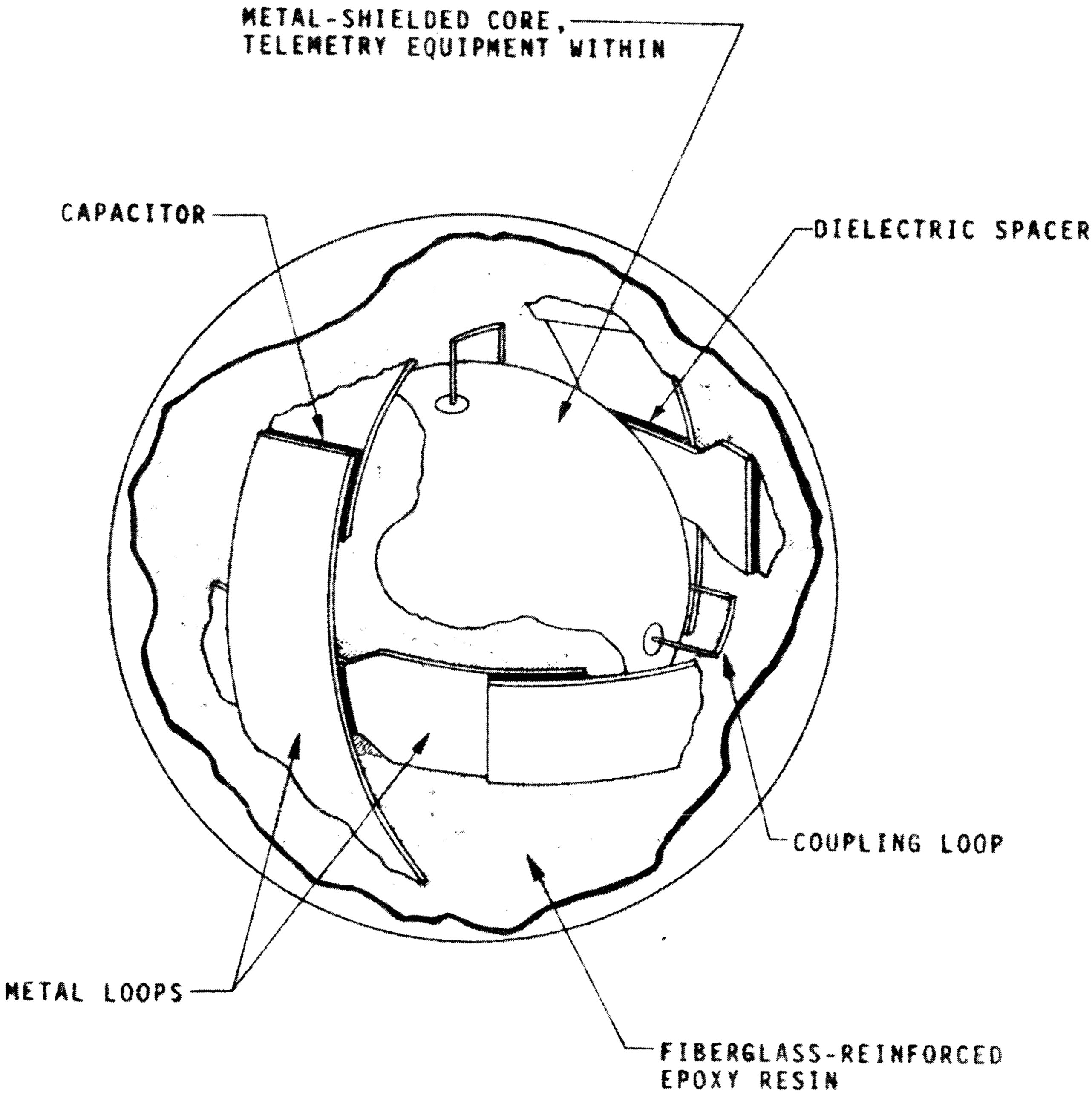

Fig. 1 - Cutaway view of crossed-loop antenna assembly.

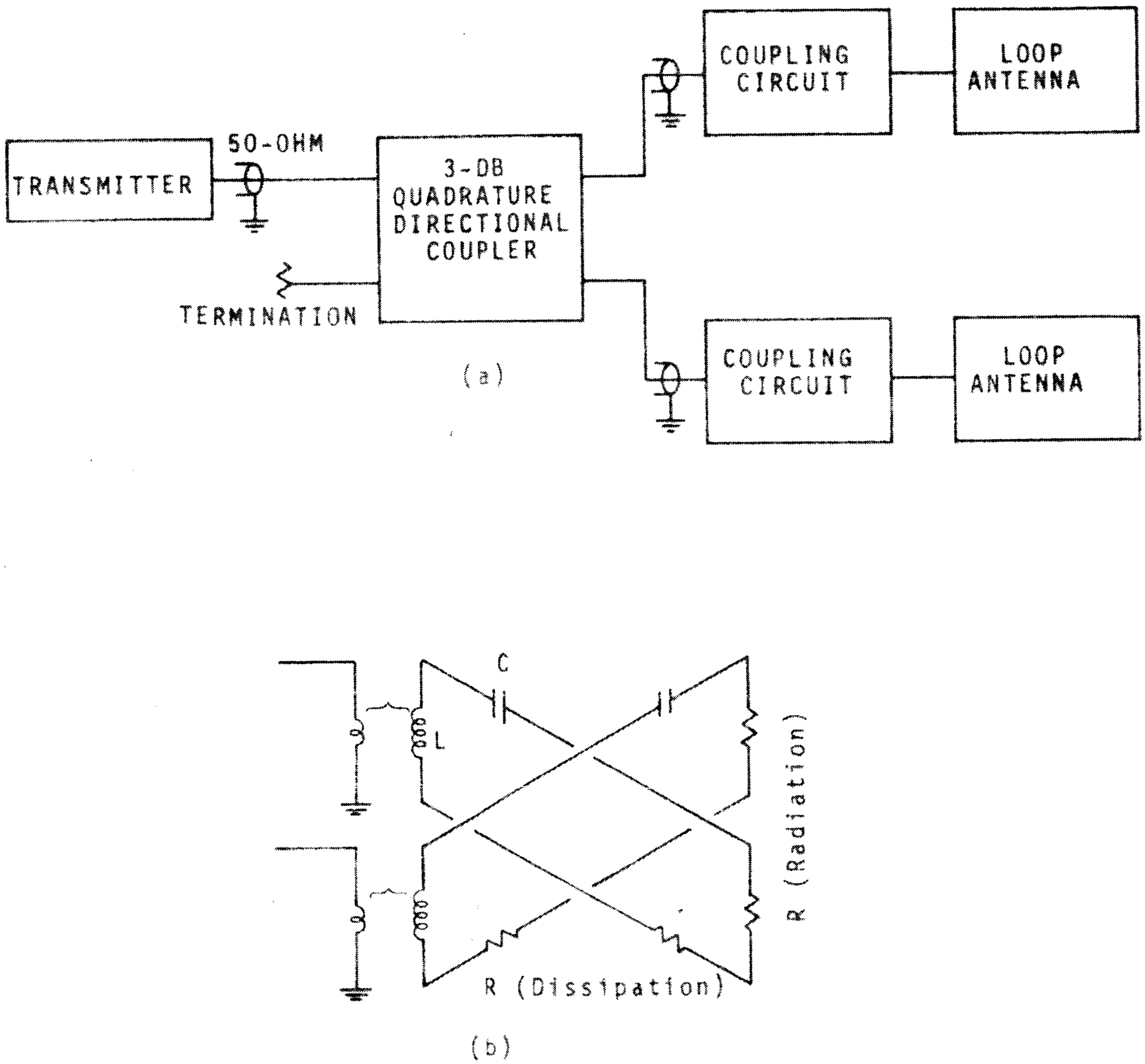

Fig. 2 - RF-circuit diagram of antenna.

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a 3-db directional coupler. At the output ports of the coupler are two equal-magnitude signals in phase quadrature. The isolated fourth port of the coupler is terminated in a matched load.

Two equal lengths of coaxial cable connect the coupler output ports to the outer surface of the central core at the locations of the coupling loops. The outer conductors of the cables are bonded to the metal core. The center conductor is shaped and bonded to the core surface to form the coupling loop. The transmitter signals are thus inductively coupled to the respective antenna loops.

The equivalent circuit of each antenna loop comprises series inductance, the series capacitance of the tuning capacitors, radiation resistance and dissipation resistance, as shown in Fig. 2(b). The dissipation resistance accounts for the total dissipative loss in the antenna loop, central core, capacitors and epoxy-resin encapsulant. Equations to compute the values of the equivalent-circuit components are presented in WL Report 1291, Section VII.

The resulting radiation pattern of this crossed-loop antenna assembly is omnidirectional, the dual of the turnstile pattern resulting from two crossed electric dipoles fed in quadrature phase.

B. Radiation-Pattern Test Model.

A prototype test model fabricated as described above is impractical for radiation pattern measurements. For the pattern tests, the batteries used to power the transmitter become discharged after long use and need to be replaced. Also, the frequency tuning control on the test transmitter must be available for adjustment. Hence, for purposes of the radiation-pattern tests, pattern-test models as shown in Fig. 3 were constructed. These models radiate in the same manner as a completely encapsulated antenna but permit replacement of batteries and tuning of the transmitter.

The encapsulation of the pattern-test model is simulated by two 3/16-inch thick hemispherical shells of fiberglass-reinforced epoxy resin. The two antenna loops are supported about the central core by six nylon screws. Within the core are located two 8.4-volt mercury batteries, a CW oscillator and a 3-db directional coupler. These components are shown in Fig. 4. The battery-access cap is shown in

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Fig. 3 - Pattern-test model.

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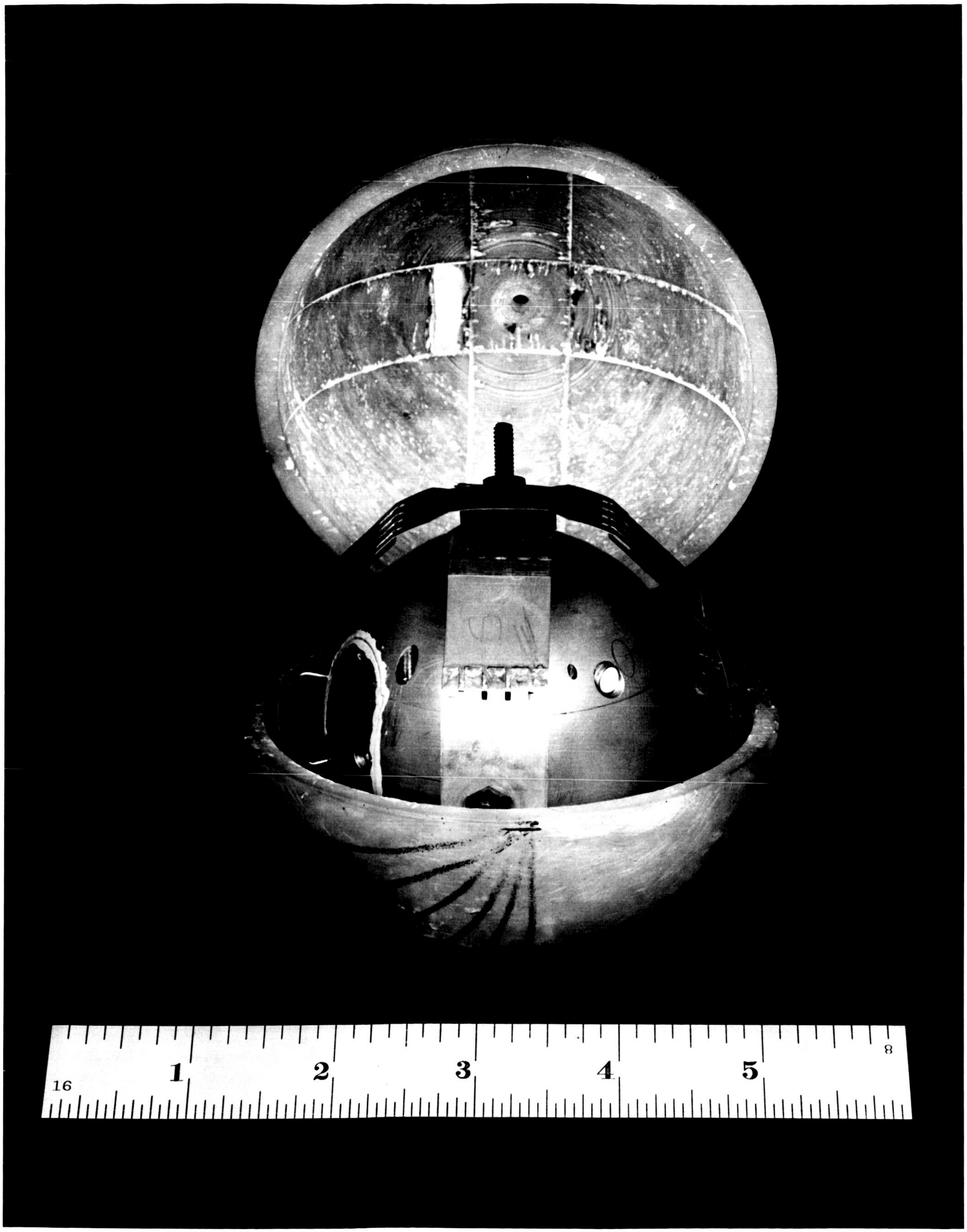

Fig. 3 - Pattern-test model.

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Fig. 4 - Oscillator, directional coupler and batteries. (Scale 1.7:1)

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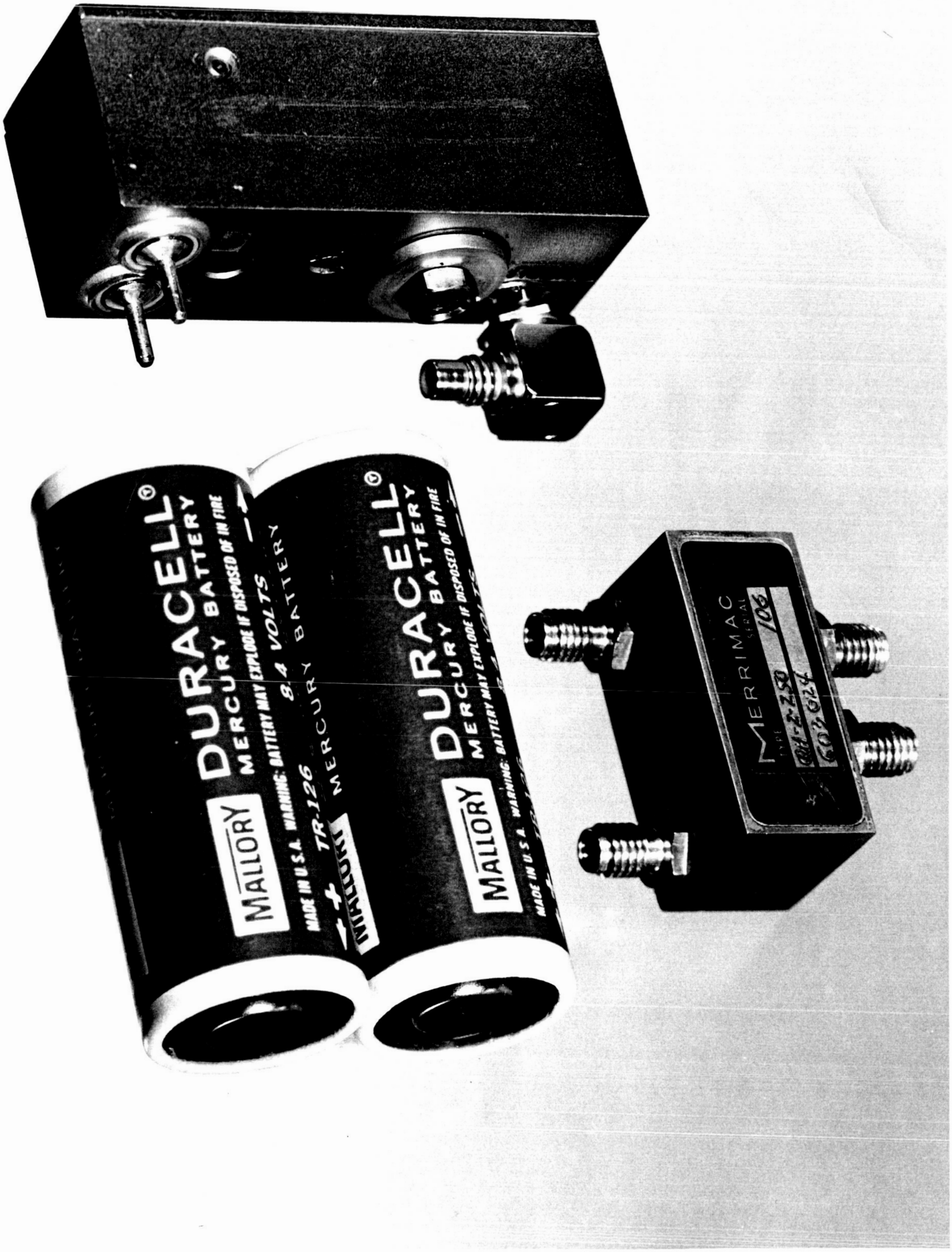

Fig. 4 - Oscillator, directional coupler and batteries.

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Fig. 4 - Oscillator, directional coupler and batteries. (Scale 1.7:1)

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Fig. 3 on the left portion of the core near one of the coupling loops.

C. Impedance-Test Model.

For the impedance tests, measurements of a model comprising a pair of antenna loops with a 3-db quadrature-coupler feed are insensitive to detuning because the reflected signals from two antenna loops tend to cancel at the input port of the coupler. For meaningful tests of the change of antenna impedance as the antenna approaches a dielectric-air interface, impedance tests of a single antenna loop should be performed. In this manner, all of the signal reflected from the detuned antenna loop under test is available for comparison with the incident signal. For this reason, an impedance-test model as shown in Fig. 5 was fabricated for the tests instead of the complete penetrometer assembly previously described. The impedance-test model comprises a pair of orthogonal antenna loops mounted about a hollow spherical core. Only one antenna loop is coupled to the external circuit. The second antenna loop is uncoupled, but is in place, to provide the blocking of the magnetic field as in the actual penetrometer assembly. The feed cable from the coupling loop associated with the active antenna loop emerges from the core at the neutral axis of the active antenna loop through a hole in the core and finally through a hole in the non-radiating antenna loop. A coaxial-cable connector is mounted at the surface of the assembly, on the end of the coaxial cable.

Complete encapsulation of the impedance-test model is necessary to simulate the impedance and dissipative-loss characteristics of each loop antenna. This is practical in this case because no active devices are necessary. The entire assembly is therefore encapsulated in the 4-inch diameter fiberglass-reinforced epoxy-resin sphere with a particular formulation specified by NASA, and described in WL Report 1291 as Mixture #1. A photo of an encapsulated impedance-test model, showing the coaxial connector at the surface, is presented in Fig. 6.

The materials used in the fabrication of these models are of interest. The central core and the antenna-loop bands of this pattern-test model are brass. The series capacitors in the antenna loops fabricated in the prior study phase were alumina. For the tests planned for this second phase, fuzed silica was selected to achieve a

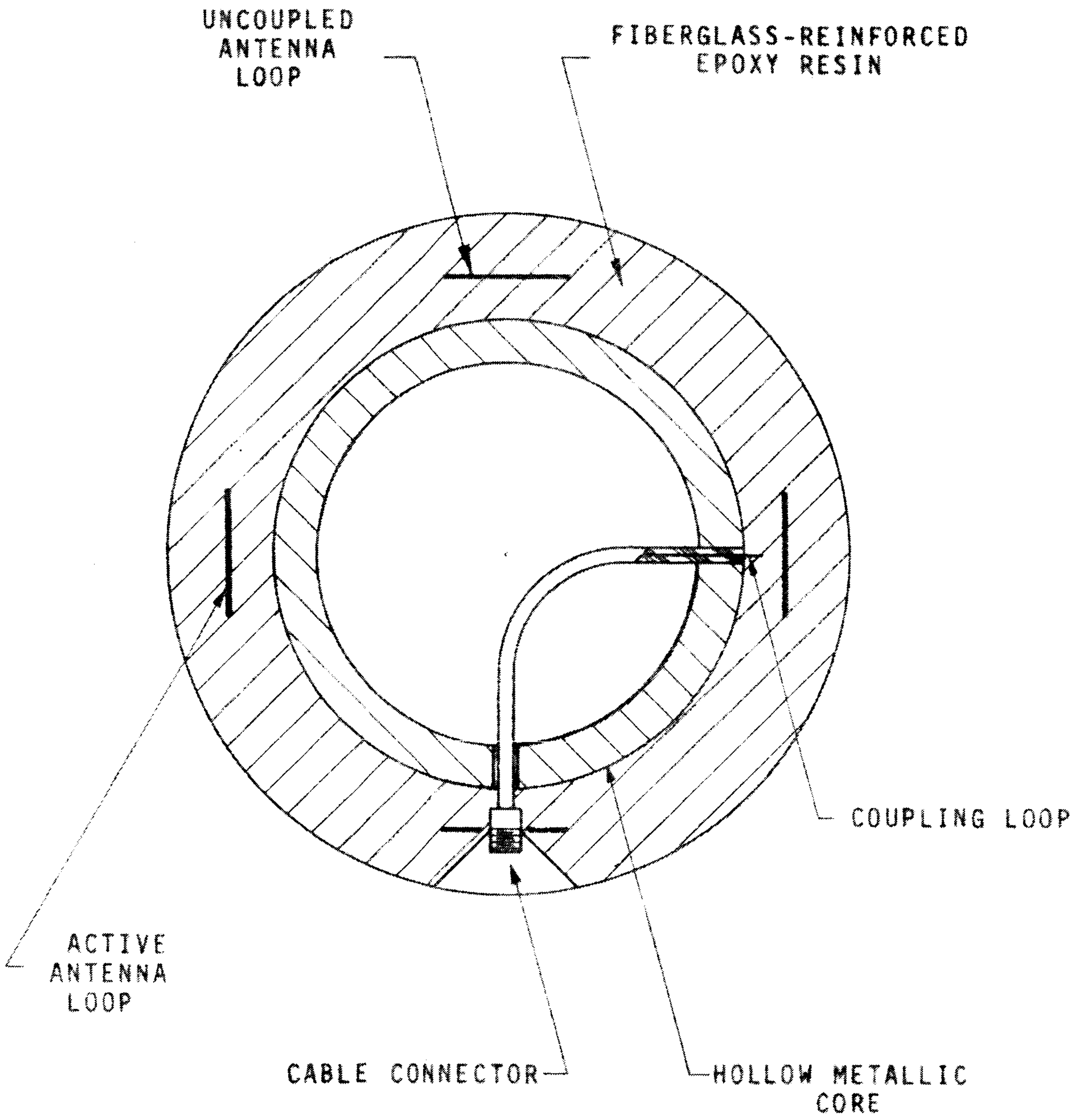

Fig. 5 - Impedance-test model (Cross-section view).

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Fig. 6 - Impedance-test model.

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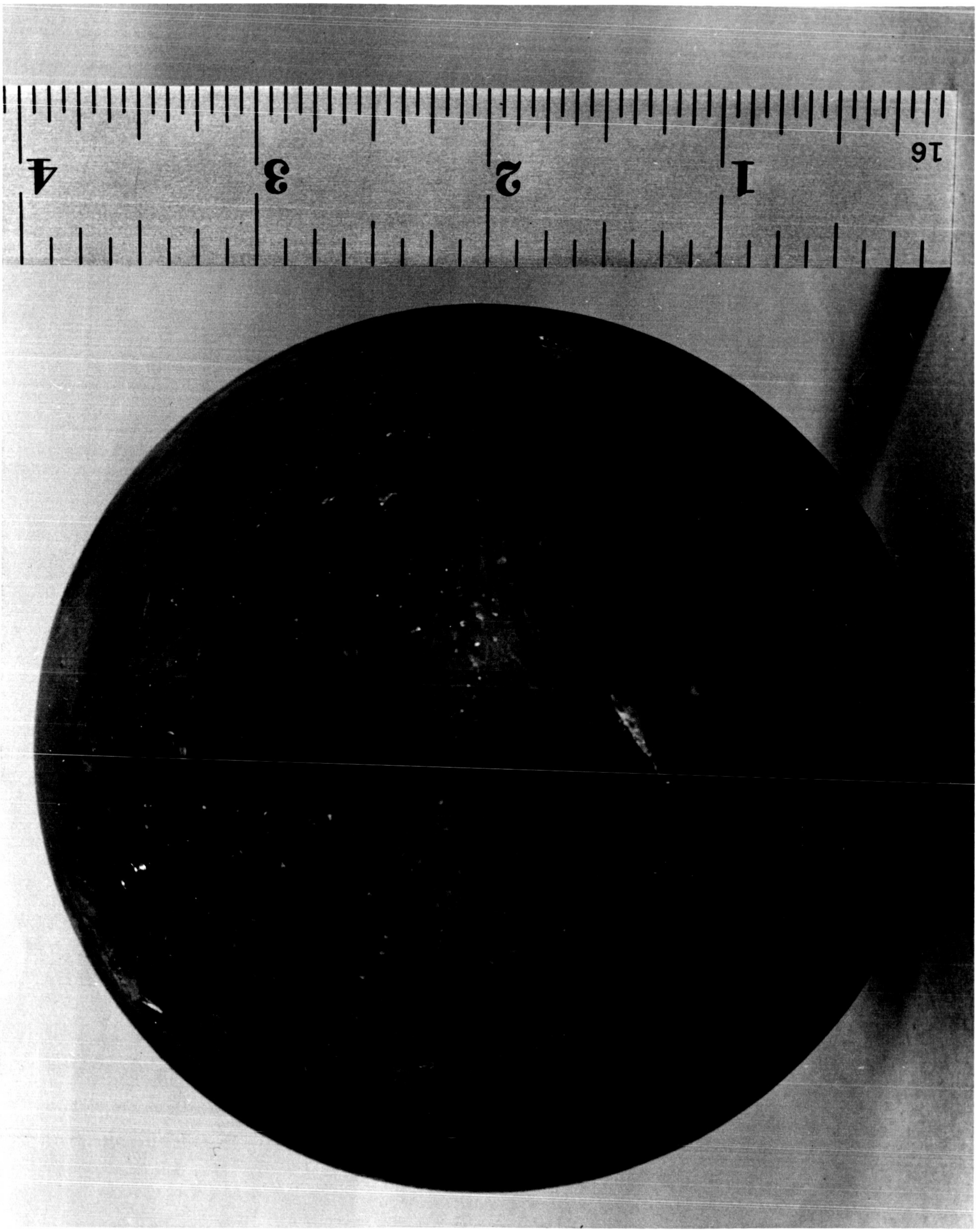

Fig. 6 - Impedance-test model.

smaller variation of capacitance with temperature. It was found that soldering the brass bands to the broad faces of the fuzed silica capacitors to form the antenna loops was difficult. The soldering procedure was successful but the resulting bond was considered too fragile to withstand the severe mechanical requirements of the penetrometer program.

The capacitors in the test models described in this report are copper-clad Rexolite 1422. This material was chosen as a useful expedient since the contract schedule did not permit the delivery time required for substituting alumina. The Rexolite 1422 has slightly more dielectric loss than either alumina or fuzed silica, and has a lower maximum working temperature. The maximum working temperature is high enough, however, to withstand the temperature generated by the exothermic setting process of the epoxy resin.

Slight tuning of the resonant frequency of the antenna loops was accomplished by trimming the copper cladding from the capacitors. For the pattern-test models, the loop capacitors were adjusted for equal resonance of the loop antennas near mid-band. Then, with both loops assembled about the core, both the contour of each loop about the core and the transmitter frequency were adjusted for as nearly equal radiation properties as possible. For the impedance-test models, the capacitors and the coupling loops were adjusted before encapsulation to compensate for the detuning effect of the encapsulant.

IV. Antenna Radiation-Pattern Measurement.

The mission plan of the penetrometer system specifies continuous radio contact between the penetrometer assembly and the spacecraft from which it is launched, for the complete time interval from launch until the end of the impact process. Hence, it is of interest to determine the full spherical radiation pattern of the penetrometer antenna located in free space, and the hemispherical radiation patterns of the penetrometer antenna approaching, making contact with, and immersing in a dielectric media. For the tests of the antenna near a dielectric-air interface, the pattern measurements include the effect of antenna detuning by the adjacent dielectric, and reflection and